DETERMINATION OF HEAT TRANSFER COEFFICIENT USING EXPERIMENTAL VALUES OF PRESSURE DROP OF A SINGLE PHASE FLUID

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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Determination of Heat Transfer Coefficient Using Experimental Values of Pressure Drop of a Single Phase Fluid*" is written by *Muhammad Bishrul Hafi bin Ab. Jalil*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I Muhammad Bishrul Hafi bin Ab Jalil hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Analogical procedure to obtain the heat transfer coefficient for fluid flowing inside tube in turbulent range with carbon nanotubes is carried out. A regression equation valid for both water and nanofluid is developed by making use of Colburn analogy to estimate the Nusselt number. Heat transfer coefficient and pressure drop with carbon nanotubes has been analogically determined with different Prandtl number and volume concentration. Based on the analysis, the regression equation showed considerable deviation with the Gnielinski correlation and considered reliable in turbulent flow for single-phase fluid. The results also showed that convective heat transfer flow in plain tube is enhanced significantly by the existence of carbon nanotubes when compared with water using the regression equation developed. It is also observed that heat transfer coefficient for carbon nanotubes having volume concentration of 0.1% is 48.16% higher compared with water at 20,000 Reynolds number. Heat transfer coefficient is also enhanced with the increase of Prandtl number and volume concentration with maximum value of 0.5%.

ABSTRAK

Prosedur berdasarkan analogi untuk menentukan pekali pemindahan haba untuk cecair yang bergerak di dalam tiub dalam lingkungan nilai turbulen telah dilaksanakan. Persamaan regresi yang sah untuk air dan cecair nano telah diterbitkan berdasarkan analogi Colburn untuk menentukan nombor Nusselt. Pekali pemindahan haba dan tekanan jatuh tiub nano karbon telah ditentukan secara analogi dengan penggunaan nombor Prandtl dan kepekatan yang berlainan. Berdasarkan analisis, persamaan regresi telah menunjukkan pensasaran nilai yang boleh diambil kira dengan persamaan Gnielinski dan boleh dianggap benar dalam aliran turbulen untuk cecair satu-fasa. Keputusan menunjukkan paksaan aliran pemindahan haba dalam tiub kosong telah ditingkatkan oleh kewujudan tiub nano karbon apabila dibandingkan dengan air menggunakan persamaan regresi yang telah diterbitkan. Selain itu diperhatikan juga bahawa pekali pemindahan haba untuk tiub nano karbon yang mempunyai kepekatan 0.1% adalah 48.16% lebih tinggi daripada air pada nombor Reynolds 20,000. Pekali pemindahan haba juga meningkat apabila nombor Prandtl dan kepekatan meningkat dengan nilai maksimum sebanyak 0.5%.

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LIST OF SYMBOLS

U	Local time averaged velocity
Θ	Temperature
u	Friction velocity
q	Rate of heat transfer flux
y	Normal distance from the wall
d	Diameter of tube
d_{np}	Diameter of nanoparticle
m	Mass
Π	Pi
$\emptyset$	Volume concentration
Re	Reynolds number
c_p	Specific heat
c_{bf}	Specific heat of base fluid
c_{nf}	Specific heat of nanofluid
c_p	Specific heat of nanoparticle
Pr	Prandtl number
Pr_w	Prandtl number of water
Pr_{nf}	Prandtl number of nanofluid
St	Stanton number
Nu	Nusselt number
f	Friction factor
$C_{\boldsymbol{d}}$	Drag coefficient
ρ	Density of fluid

ρ_{nf}	Density of nanoparticle
ρ_p	Density of nanoparticle
ρ_{bf}	Density of base fluid
k	Thermal conductivity
k_{nf}	Thermal conductivity of nanofluid
k_{bf}	Thermal conductivity of base fluid
T_{nf}	Temperature of nanofluid
μ	Dynamic viscosity
μ_{nf}	Dynamic viscosity of nanofluid
T_b	Bulk temperature
T_w	Temperature of water
h	Heat transfer coefficient

LIST OF ABBREVIATIONS

SWCNTs	Single-walled carbon nanotubes
MWCNTs	Multi-walled carbon nanotubes
VEROS	Vacuum Evaporation onto a Running Oil Substrate
SANSS	Submerged Arc Nanoparticle Synthesis System
CTAB	Oleic acid and cetyltrimethylammoniumbromide
CNTs	Carbon nanotubes
TCNT	Treated carbon nanotube
PCNT	Pristine carbon nanotube
FYP	Final year project

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nanofluids are fluids containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Water, oil and ethylene glycol are the conventional heat transfer fluids. Nanofluids are able to enhance the thermal properties in term of thermal conductivity and heat transfer coefficients compared to the conventional heat transfer fluids. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engine. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid.

Carbon nanotube is one of the nanoparticles used to produce the nanofluids. Since the first discovery of carbon nanotube in 1991, there have been a lot of experimental, simulation and theoretical investigations on electronic, anisotropic mechanical and adsorptive properties of carbon nanotube. There are two types of carbon nanotube which are single-walled and multi-walled carbon nanotube depending on the synthesis conditions. Nanotubes can be single-walled (a single tubule of 1 nm) or multi-walled (2–50 tubules of 2–50 nm positioned concentrically).

Single-walled carbon nanotubes (SWCNTs) are often found in self-organized bundles. For example, a set of aligned tubes arranged in a two-dimensional triangular lattice in the plane perpendicular to their common axes is categorized as SWCNTs. One of the applications of SWCNTs bundles is field emission electron sources for flat panel display to which both mechanical and electrical properties are important and coupled. It has been predicted that radial deformation, resulting in polygonized cross-sections, alters the band gap, leading to changes in the electron transport characteristics of carbon nanotubes.

Meanwhile, multi-walled carbon nanotubes (MWCNTs) consist of many graphite layers concentrically nested like rings of a tree trunk. MWCNTs was reported to have lower mechanical performance than the SWCNTs, but can be produced in a much larger quantity and at a lower cost. MWCNTs have been investigated for a variety of applications based on its unique electrical, optical, and mechanical properties. While such properties are truly significant, the practical realization of reproducible performance in devices such as field effect transistors, high-strength composite materials, sensors, actuators, and catalyst supports will require material standardization, especially in terms of length and degree of distribution. Rational chemical functionalization of carbon nanotubes is important for predictive manipulation of these nanotubes. MWCNTs is also more rigid because their section is much larger compared to that of SWCNTs. MWCNTs have been proven to be very effective fillers especially in tailored polymeric materials suited to prescribed applications at very low loadings. This is because neat MWCNTs exhibit excellent mechanical, thermal, and electrical properties. One of the advantages of MWCNTs used as filler is their high aspect ratio, as high as 1000, which can induce better adhesion with the polymeric matrix, which is an important factor for effective enhancement of the nanocomposite's properties. This enables percolation of the fillers at very low concentrations and makes them attractive for use in a broad spectrum of applications, especially as reinforcing fibers in nanocomposites.

1.2 PROBLEM STATEMENTS

During the study on nanofluids, it was found out that the knowledge on nanofluids is very limited. Thus, the determination of heat transfer coefficient for nanofluids is much difficult. Further understanding is needed regarding impact of particle size, shape, concentration, temperature and pH. This problem however can be overcome by conducting the pressure drop experiment. However, due to the expensive cost of conducting experiment and involves a lot of time, an analogy is proposed instead of scientific experiment setup in order to estimate the heat transfer coefficient of nanofluids.

1.3 PROJECT OBJECTIVE

The objectives of this project are:

1. Propose an analogy to estimate the heat transfer coefficients of CNTs
2. Develop a regression equation in the similar manner as Colburn analogy to evaluate the heat transfer coefficient for internal flow
3. The equation should have the flexibility to estimate Nusselt number of single phase fluid in the absence of nanoparticles

1.4 PROJECT SCOPES

Heat transfer coefficient of pure fluids can be estimated by making use of Colburn analogy, thus similar approach is proposed to be undertaken for nanofluids also.

The scopes of this project are:

1. Compare the thermophysical experimental data of MWCNTs nanofluid with available property equations
2. Develop an equation for the estimation of nanofluid heat transfer coefficient using the concept of analogy for water based nanofluids
3. Estimate the Nusselt number and heat transfer coefficient for MWCNT nanofluid at different concentrations, Prandtl number and temperatures.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discusses about the previous related study and researches on nanofluids. The sources of the review are extracted from journals, articles, reference books and internet. The purpose of this section is to provide additional information and relevant facts based on past researches which related to this project. This chapter will cover the corresponding terms such as the Colburn analogy, fundamentals of nanofluids, heat transfer and the enhancement of heat transfer caused by nanofluids which had been proved experimentally.

2.2 THE COLBURN ANALOGY

Colburn analogy is the most successful and widely used analogy on heat, momentum and mass transfer analogies for pure fluid. The basic mechanisms and mathematics of heat, mass and momentum transport are essentially the same. Among other analogies such as Reynolds analogy and Prandtl-Taylor analogy, Colburn analogy was developed to relate the heat transfer coefficients with the friction factors directly for flow inside tube. This analogy is proved to be the most accurate analogy in heat and mass transfer problem.

Pure fluid such as water flowing inside circular horizontal tube will results to the existence of friction between water and the internal part of the tube which is called the friction factor. By using the Colburn analogy, also knowing the Prandtl and Stanton number, the heat transfer coefficient for external flow can be determined using the expression below;

$$St.Pr^{2/3} = \frac{f}{2}$$

Since the project is focused on the internal turbulent flow, the equation is given by;

$$St.Pr^{2/3} = \frac{f}{8}$$

where;

St = Stanton number

Pr = Prandtl number

f = friction factor

2.2.1 The Derivation of Colburn Analogy

The velocity and temperature profiles can be expressed in terms of a log-law and a power law. The power law form is;

$$\frac{U}{U_\infty} = \left(\frac{y}{\delta_{m,t}}\right)^p \qquad (1)$$

$$\frac{\Theta - \Theta_w}{\Theta_\infty - \Theta_w} = (\frac{y}{\delta_{h,t}})^{p'} \qquad (2)$$

where U and Θ are the local time averaged velocity and temperature and the suffices w, ∞ refer to values at the wall and at an infinite normal distance in fact at the edge of the boundary layer.

The logarithmic form is

$$U^+ = 2.5 \ln y^+ + B \qquad (3)$$

$$\Theta^{+} = 2.5 \ln y^{+} + B' \tag{4}$$

where;

$U^{+} = \dfrac{U}{u}$

$y^{+} = yu\,\frac{\rho}{\mu} = \frac{yu}{v}$

$\Theta^{+} = \rho c_p(\Theta - \Theta_w)u/q_w$

$u = \dfrac{\sqrt{t_w}}{\rho}$

In this analysis, we pass equation (1) through the Kolmogorov point which is the intersection of the log law with the equation;

$$U^{+} = y^{+} \tag{5}$$

The coordinates of this Kolmogoroff point are $y_k^{+} = U_k^{+} = 11.8$, substituting into equation (1) and rearranging we obtain;

$$\delta_{m,t} = 11.8\left(\frac{U_\infty^{+}}{11.8}\right)^{1/p} \tag{6}$$

Now the intersection between equation (4) and the diffusive equation at the wall,

$$\Theta^{+} = y^{+}Pr \tag{7}$$

is 11.8 Pr^{-b}, 11.8 Pr^{1-b}. Substituting into equation (4) gives;

$$\delta_{h,t} = 11.8Pr^{-b}\left(\frac{\Theta_\infty^{+}}{11.8Pr^{1-b}}\right)^{1/p'} \tag{8}$$

Then the ratio between the turbulent thermal and momentum boundary layers $\delta_{h,t}^{+}, \delta_{m,t}^{+}$ becomes;

$$\sigma_t = \frac{\delta_{h,t}}{\delta_{m,t}} = \frac{\Theta_\infty^{+1/p'}}{U_\infty^{+1/p}} Pr^{-b-\frac{1-b}{p'}} 11.8^{\frac{1}{p}-\frac{1}{p'}} \tag{9}$$

We now apply Reynolds' analogy by stating;

$$p = p' \tag{10}$$

Then;

$$\sigma_{t} = \left(\frac{\Theta_\infty^+}{U_\infty^+}\right)^{1/p} Pr^{\frac{b-bp-1}{p}} \tag{11}$$

By definition, for a boundary layer;

$$\frac{\Theta_\infty^+}{U_\infty^+} = \frac{f/2}{St} \tag{12}$$

and

$$\sigma_{t} = \left(\frac{f/2}{St}\right)^{1/p} Pr^{\frac{b-bp-1}{p}} \tag{13}$$

The Stanton number is obtained from the integral energy equation (Knudsen & Katz, 1958)

$$St = \frac{\partial}{\partial x}\int_0^{\delta_{h,t}} \frac{U}{U_\infty}\left[1 - \left(\frac{\Theta-\Theta_W}{\Theta_\infty-\Theta_W}\right)\right] dy \tag{14}$$

Substituting for (1) and (2);

$$St = \frac{\partial}{\partial x}\int_{0}^{\delta_{h,t}} \left(\frac{y}{\delta_{m,t}}\right)^{p}\left[1-\left(\frac{y}{\delta_{h,t}}\right)^{p'}\right]dy \tag{15}$$

$$St = \frac{\partial}{\partial x}\left[\frac{p\delta_{m,t}}{(1+p)(1+p+p')\sigma_t^{p+1}}\right] = \left[\frac{p\sigma_t^{p+1}}{(2p+1)(p+1)}\right]\frac{\partial\delta_{m,t}}{\partial x} \tag{16}$$

Most experimental data show that the ratio $\frac{f/2}{St}$ is independent of x and equation (13) indicates then that we can take σ_t to be independent of x. Then;

$$St = \left(\frac{\delta_{m,t}}{x}\right)\left[\frac{p\sigma_t^{p+1}}{(2p+1)(p+1)}\right] \tag{17}$$

The friction factor can be expressed as $\delta_{m,t}$ can be estimated from the integral momentum equation by standard techniques. The friction factor can be expressed as;

$$f = \frac{\alpha}{Re_g^{\beta}} \tag{18}$$

Giving (Skelland and Sampson, 1973, Trinh, 2010)

$$p = \frac{\beta}{2-\beta} \tag{19}$$

And

$$\frac{\delta_{m,t}}{x} = \left[\frac{\alpha(\beta+1)(\beta+2)}{\beta(2-\beta)}\right]^{1/\beta+1}\left[\frac{v}{U_\infty x}\right]^{\beta/\beta+1} \tag{20}$$

$$\frac{\delta_{m,t}}{x} = \left[\frac{\alpha(1+3p)(1+2p)}{2p}\right]^{1+p/1+3p}\left[\frac{v}{U_\infty x}\right]^{2p/1+3p} \tag{21}$$

Combining (13), (17) and (21), and rearranging gives;

$$St = \frac{f}{2} Pr^{(b-bp-1)\frac{p+1}{p+2}} \tag{22}$$

Putting b=1/3 for high Schmidt numbers, (Trinh, 2010b) and p=1/7 (Blasius, 1913) gives;

$$St = \frac{f}{2} Pr^{-0.63} \tag{23}$$

The study of heat and mass transfer in turbulent flows has been heavily influenced by the formulation of an analogy with the better known law for momentum transfer by Colburn. Thus, analogy proposed in this project is developed in the similar manner as Colburn analogy.

2.3 CONVENTIONAL HEAT TRANSFER FLUIDS

Conventional heat transfer fluids such as water, oil and ethylene glycol were commonly used in heat and mass transfer experiments but their applications are limited due to the poor capabilities in term of thermal properties. They also exhibit poor heat transfer performance and therefore high compactness and effectiveness of heat transfer systems are necessary to achieve the required heat transfer. In the past years, many different techniques were utilized to improve the heat transfer rate for these conventional heat transfer fluids in order to reach a satisfactory level of thermal efficiency. However, the heat transfer rate can passively be enhanced by changing the flow geometry, boundary conditions or by improving the thermophysical properties of the heat transfer fluids to increase the fluid thermal conductivity. However, there is one way to enhance the thermal conductivity which is by adding small size solid particles in the fluid. According to the past research conducted by J.C. Maxwell, thermal conductivity of a solid-liquid mixture can be increased by using more volume fraction of solid particles. In the experiment, particles of micrometer or millimeter-sized dimensions were used. The results showed some enhancement but at the same time